Performance Analysis of Slowed Rotor Compound Helicopter

SHAH Suman, *HAN Dong**, *YANG Kelong*

College of Aerospace Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, P. R. China

(Received 20 July 2020; revised 5 September 2020; accepted 18 September 2020)

Abstract: The performance of slowed-rotor compound aircraft, particularly at high-speed flight condition, is examined. The forward flight performance calculation model of the composite helicopter is established, and the appropriate wing and propeller parameters are determined. The predicted performance of isolated propeller, wing and rotor combination is examined. Three kinds of tip speed and a range of load share setting are investigated. Propeller bearing 80% of the thrust with wing sharing lift is found to be the best condition to have better performance and the maximum L/D for maximum forward speed. Detailed rotor, propeller, and wing performance are examined for sea level, 1 000 m, and 2 000 m cruise altitude. Rotor, propeller, and wing power are found to be largely from profile drag, except at low speed where the wing is near stall. Increased elevation offloads lift from the rotor to the wing, dropping the total power required and increasing the maximum speed limit over 400 km/h.

Key words: compound helicopter; wing; propeller; flight performance; lift distribution; thrust distribution

CLC number: V211.52 **Document code:** A **Article ID:** 1005-1120(2020)S-0009-09

0 Introduction

Since time immemorial, humankind has been dreaming of flying with unconstrained freedom together with full motion control. The helicopter, as it is currently known, is by far the flying vehicle that more closely satisfies that demand due to its inherent flying characteristics—its ability to take-off and land vertically, and to hover for extended periods, as well as its handling properties under low airspeed conditions. This idea is patent in the following citation from Igor Sikorsky, "The helicopter approaches closer than any other (vehicle) to the fulfillment of mankind's ancient dreams of the flying horse and the magic carpet."

Compared with fixed-wing aircraft, helicopters display the characteristics of vertical lifting, low-altitude hovering and high maneuverability at low speeds, which makes the helicopters play an irreplaceable role in various fields of military and civilian use, such as search and rescue, and military applications. However, its speed, range, and ceiling are not as good as fixed-wing aircraft. The maximum forward speed of conventional helicopters can only reach about 300 km/h, which is far from meeting its performance requirements. The pursuit of high speed, long-range, and a high ceiling has become an inevitable trend in the future development of helicopters.

A compound helicopter complements the supplementary lifting and/or thrusting device, which allows the main rotor to relieve both lift and propulsion requirements in forwarding flight. Additional thrust and auxiliary control surfaces also acquaint with redundant controls which along with the decreased loading, allow trimming of the rotor to improve performance and enlarge the mission envelope while upholding tolerable hover performance. However, these benefits must be balanced against the added weight, mechanical difficulty, and aerodynamic interference of the additional components. Currently, much work has been engrossed on tilt-rotor aircraft; both military and civilian tilt rotors. But other configurations may provide analogous benefits

*Corresponding author, E-mail address: donghan@nuaa.edu.cn.

How to cite this article: SHAH Suman, HAN Dong, YANG Kelong. Performance analysis of slowed rotor compound helicopter[J]. Transactions of Nanjing University of Aeronautics and Astronautics, 2020, 37(S): 9-17.

http://dx.doi.org/10.16356/j.1005-1120.2020.S.002

to tilt rotors in terms of range and speed. A downside is that the rotor must be slowed at high speed to lighten compressibility and drag divergence effects on the advancing side.

There are numerous examples of helicopter that contained some thrust and/or lift compounding as shown in Ref.[1], which provides valuable information about the competences and restrictions of compound configurations. Also, the operational benefits of a compound configuration versus other high-speed concepts are discussed. There have also been numerous design studies exploring the performance of compound helicopters[2-8]. However, these generally focused on restricted flight conditions or used simplified analysis models, but none estimated the blade loads.

Refs.[2-3] used CAMRAD II software to analyze the aerodynamic characteristics of the high-speed helicopter. The parameters, such as the lift-to-drag ratio and other performance changes, were used to determine the optimum torque, tip speed, and other parameters such as growth in the efficiency of the wing. Ref.[4] pointed out that the rotor plused the combination of the wings could significantly increase the lift-to-drag ratio of the rotor system and the low-speed rotor could reduce the power required by the helicopter. Refs.[5-6] used a multi-fidelity approach with the NASA design and analysis of rotorcraft code (NDARC) and CAMRAD II to design and study the performance of different compound helicopter configurations. Ref.[7] investigated the use of redundant controls on a compounded UH-60A-like helicopter to improve performance at a high airspeed condition. Ref.[8] investigated the decrease in fixed frame vibratory loads when supporting thrust, lift, and terminated controls were applied.

This paper is to investigate the limiting performance and loads of a single main rotor compound configuration using the UH-60A helicopter as the research object, validate the compound form with wing and propeller, determine the influence of lift and thrust distribution on the total power and lift-to-drag ratio of the helicopter, and then explore the advantages of adding the wing and propeller to improve the flight performance of the helicopter.

1 Modeling

The modeling method in Ref.[9] based on the blade element theory establishes the rotor model. The blade adopts the rigid beam model with the flapping hinge extension. The Mach number and the angle of attack of the position of the blade element, and the airfoil parameter table of the wing type are obtained. The aerodynamics of its profile and the rotor induced velocity are calculated using the Pitt-Peters dynamic inflow model[10]. The flapping motion affects the aerodynamic and moment calculations. According to the balance of the moment of inertia force, gravity and aerodynamic force on the swing hinge, the swing response is obtained by iterative convergence, and then the force and torque on the rotor are calculated. At any point, the flapping response is calculated using Wayne Johnson's empirical method[11]. The fuselage is treated as a rigid body with specified aerodynamic force and moment. For simplicity, the thrust of tail rotor is determined by the main rotor torque(Q_{MR})

$$T_{\mathrm{TR}}=\frac{Q_{\mathrm{MR}}}{l_{\mathrm{TR}}} \tag{1}$$

where l_{TR} is the distance between the tail rotor hub and the center of gravity of the helicopter in the x-axis direction of the body axis system. The power required and collective pitch of tail rotor are determined by blade element theory with uniform inflow. The addition of a propeller has been taken into account in the force summation by adding a horizontal force in the opposite direction and it is proportional to the aircraft airframe drag. The momentum theory is used to solve the propeller induction speed, assuming that the airflow is an incompressible ideal gas, and the tension generated by the blade is evenly distributed. The schematic diagram of the flow through the propeller blade is shown in Fig.1. V_0 is the forward speed of the helicopter. Due to the slipstream, the axial velocity component is increased to V_x, and the circumferential velocity component is reduced to V_θ due to the rotation of the airflow induced by the rotation of the propeller[12].

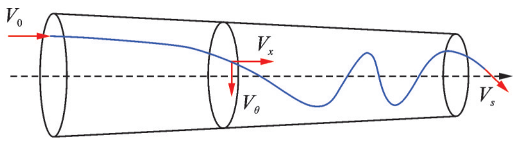

Fig.1 Air flow through propeller

The aerodynamic and torque calculations for the wing[13], here to simplify the model, assume that the yaw aileron deflection angle is 0, only consider the lift-drag generated by the wing, and the forward airflow speed from the far side. The flow velocity and the induced velocity of the rotor on the wing are superimposed and decomposed along the body axis. Look-up table airfoil aerodynamics is used to calculate the lift coefficient $C_l(\alpha, Ma)$ and drag coefficient $C_d(\alpha, Ma)$ of the blade element according to the local resultant air flow and angle of attack, where Ma is Mach number and α the angle of attack.

For the given pitch control and rotor shaft altitude angle, the periodic response of the rotor in steady forward flight can be obtained for a prescribed forward speed. The hub force and the moment of main rotor are balanced by the force and moment acting on fuselage, tail rotor, propeller and wing. The force and moment on the fuselage are determined by the flight state and altitude angle. The thrust and power of the tail rotor are derived from the rotor torque and flight state. These force and moment components constitute the equilibrium equations of the helicopter

$$W - T_{\mathrm{MR}} - T_{\mathrm{W}} = 0 \tag{2}$$

$$D + H_{\mathrm{MR}} + D_{\mathrm{W}} - T_{\mathrm{MR}}\theta_{\mathrm{F}} - T_{\mathrm{P}} = 0 \tag{3}$$

$$Y_{\mathrm{MR}} + T_{\mathrm{TR}} + T_{\mathrm{MR}}\phi_{\mathrm{F}} = 0 \tag{4}$$

$$M_{y\mathrm{MR}} + W(h\theta_{\mathrm{F}} - x_{\mathrm{CG}}) - hD = 0 \tag{5}$$

$$M_{x\mathrm{MR}} + W(h\phi_{\mathrm{F}} - y_{\mathrm{CG}}) + T_{\mathrm{TR}}h_{\mathrm{TR}} - Q_{\mathrm{P}} = 0 \tag{6}$$

$$Q_{\mathrm{MR}} - T_{\mathrm{TR}}l_{\mathrm{TR}} = 0 \tag{7}$$

where T_{MR}, h, H_{MR}, $M_{y\mathrm{MR}}$, Q_{MR} and $M_{x\mathrm{MR}}$ are the rotor thrust, drag force, side force, pitching moment, rotor torque and rolling moment. D is the fuselage drag. T_{W}, and D_{W} are the wing thrust and the wing drag. W is the weight of helicopter. x_{CG}, y_{CG}, and h are the longitudinal, lateral, and vertical distance from center of mass to rotor hub center. θ_{F}, and ϕ_{F} are the pitch angle and the roll angle of fuselage. T_{TR}, l_{TR} and h_{TR} are the tail rotor thrust, the longitudinal and the vertical distance between the center of gravity and the hub of tail rotor. T_{P} and Q_{P} are the propeller thrust and the propeller torque. After several iterations of the periodic rotor responses and solutions of the equilibrium equations, the converged or trimmed pitch controls and rotor attitude can be obtained. The flowchart of the performance prediction method is shown in Fig.2.

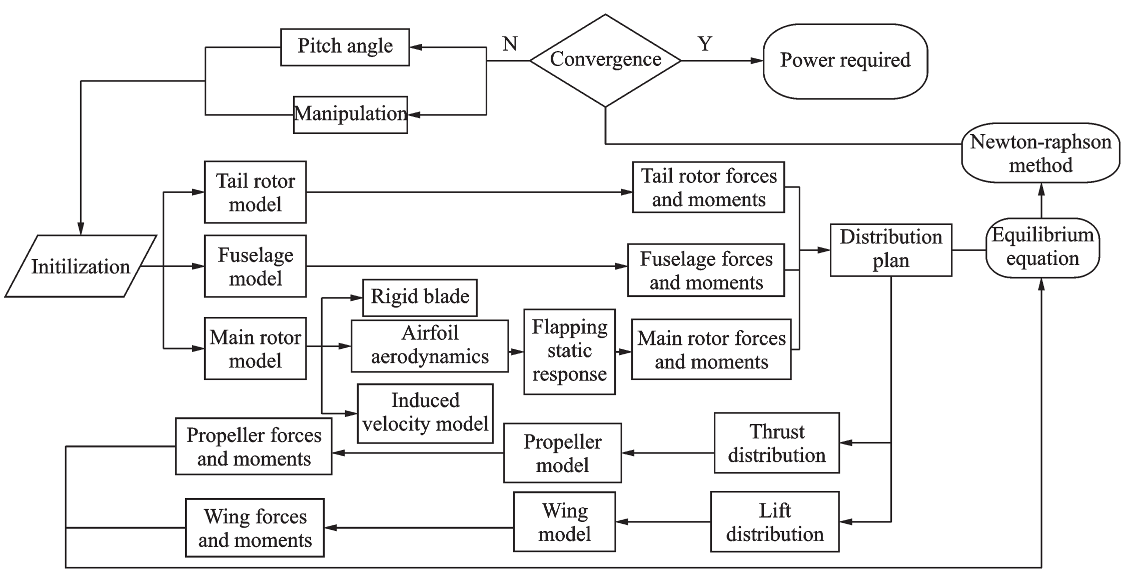

Fig.2 Trim initialization flowchart

2 Validation

The flight test data of the UH-60A helicopter is utilized to validate the model used in the paper. The parameters of the main and tail rotor are listed in Table 1[14-15]. For the performance analysis, only the aerodynamic drag force is considered in fuselage model. The fuselage drag equation utilized in the present analysis is[16]

$$\frac{D}{q}\,(ft^2)=35.83+0.016\times(1.66\alpha_s^2) \tag{8}$$

where D is the fuselage drag, q the dynamic pressure and α_s the aircraft pitch angle. The distance of the tail rotor to the rotor shaft is 9.93 m. The vertical distance from the center of mass of the helicopter to the rotor hub is 1.78 m. The comparison of the prediction of the rotor power with the flight test data for the take-off weight coefficient (C_W) 0.006 5, 0.007 4, 0.008 3, and 0.009 1 are shown in Fig.3. It is obvious that the predictions of the present method are generally in good arrangement with the flight test for the weight considered. This proves that the present method is reasonable for helicopter performance analysis. This model has been used for dynamic blade twist on rotor performance[17]. The weight coefficient expression is

$$C_W=\frac{W}{\rho\pi R^2\Omega_R^2} \tag{9}$$

In order to verify whether the propeller aerodynamic model can be used to calculate the propeller thrust and power, the numerical model is used to calculate thrust coefficient, power coefficient and efficiency of the propeller in Ref.[12], and compared with the wind tunnel test results[18]. As the propeller airfoil is Clark-Y type, there is a airfoil parameter table, and the empirical formula fitted by profile software is used to simulate the curve of the propeller thrust coefficient(C_T) and the power coefficient(C_P) to the forward ratio (V/nD), where V is the forward speed, n the rotational speed of propeller, and D the diameter of propeller, as shown in Fig.4. The parameters for propeller are shown in Table 1.

Table 1 Parameter of the main and tail rotor[14-15]

Parameter	Rotor	Tail Rotor	Propeller
Radius/m	8.18	1.68	1.65
Ω_R/(rad•s^{-1})	27.0	124	188
Blade chord length/m	0.527	0.247	0.2
Blade twist/(°)	Nonlinear	−18	−18
Blade airfoil	SC1095/ SC1094R8	NACA-0012	CLARKY-Y
Number of blades	4	4	8
Flap hinge offset/m	0.381	—	—
Blade mass per unit length/(kg•m^{-1})	13.9	—	—
Longitudinal shaft tilt/(°)	3	—	—

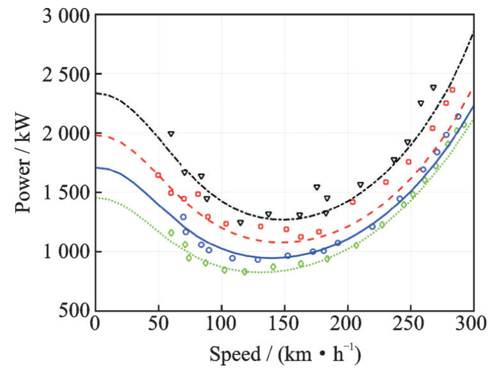

Fig.3 Comparison of calculated data and test data

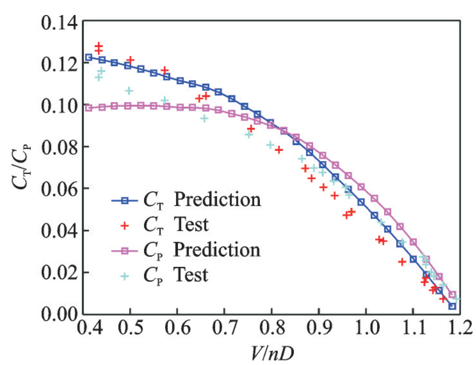

Fig.4 Comparison of calculated data and test data for propeller

3 Results

3.1 With propeller

The helicopter weight coefficient is 0.006 5, the propeller installation angle varying from 63° at root and 23° at tip. The total power P is the sum of the rotor required power P_{MR}, the tail rotor required power P_{TR} and the propeller required power P_P, namely

$$P = P_{MR} + P_{TR} + P_P \tag{10}$$

The total power is also increased due to the increase of the propeller power. The propeller power increases slightly at the medium and low speeds, but the change is small. At high speed, the power required by the propeller is increased depending on the percentage engagement of the propeller. If propeller thrust used is decreases, the required main rotor power is increased significantly. So, from a wise trade-off of 80% propeller thrust is worthy, as shown in Fig.5. There is no significant change in the rotor power because of propeller radius(R_P), but total power increases with the increase of the propeller radius, because the required power of propeller increases. At medium and low speeds, the addition of the propeller device dramatically increases the total power of the helicopter. At this time, the propeller is not conducive to improve the flight performance of the helicopter. At high speed (speed exceeding 180 km/h), the total power decreases to some extent, but the change is not apparent. From Fig.6, when the propeller radius is less than 1.65 m, the total power is closer to the baseline value at lower speed. As the radius further decreases, the total power may decrease. However, if the propeller speed is too low, it may cause the propeller to fail to provide enough thrust as the effective area of the disc decreases. The minimum value is obtained at

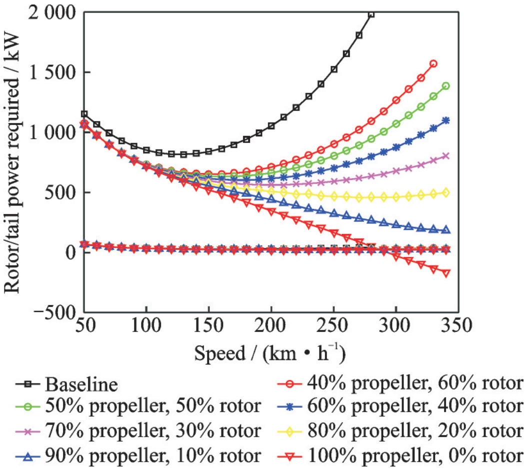

Fig.5 Rotor power vs speed at 90% Ω_R

1.5 m. When the rotational speed increases, the total power increases. Thus, for a trade-off of 1.65 m is an excellent optimal value for propeller radius. It can be further observed from Fig.7 that at at propeller rotational speed Ω_P=200 rad/s, the maximum L/D ratio is close to baseline curve, so there is no performance improvement at speeds of more than 188 rad/s, but further decrease of rotational speed of propeller may also lead to failure of propeller to provide enough thrust for forward flight.

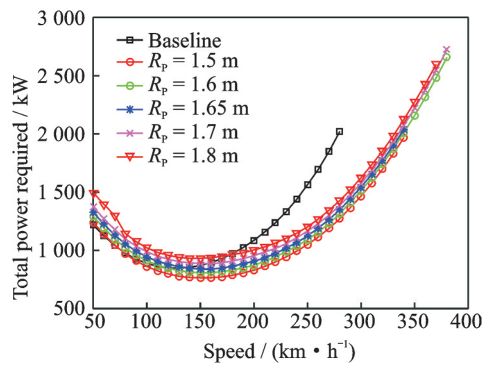

Fig.6 Total power vs speed at 90% Ω_R for 80% propeller and 20% rotor thrust at 188 rad/s

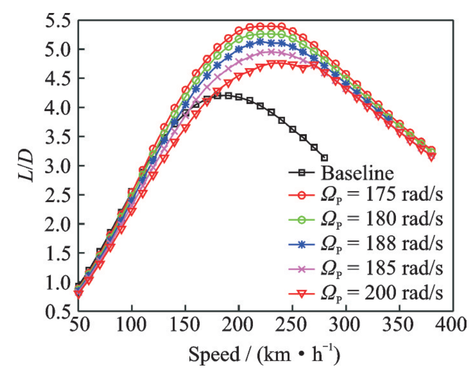

Fig.7 L/D vs speed at 90% Ω_R for 80% propeller and 20% rotor thrust

3.2 With wing

In the flight performance calculation model, the lift resistance provided by the wing is determined by the given wing installation angle. Fig.8 shows the total power variation with forward flight speed at five installation angles (ϕ_W) when the helicopter weight coefficient is 0.006 5, and the flight altitude is 0 m.

$$P = P_{MR} + P_{TR} \tag{11}$$

In Eq.(11), the wing drag is balanced by the rotor thrust, so the required power P_W of the wing

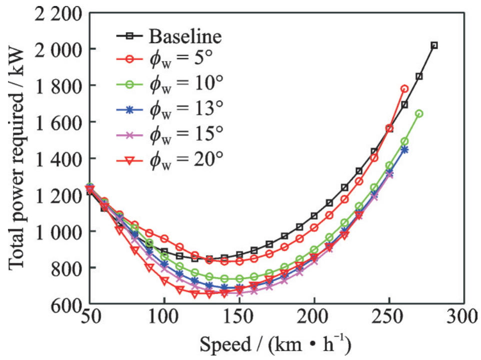

Fig.8 Total power vs speed at 90% Ω_R

is included in the rotor power. At low speeds, the addition of the wing increases the total power of the helicopter, and the smaller the installation angle is, the greater the total power will increase. When the speed increases to 100—200 km/h, the total power is reduced. With a mounting angle of 15° and 20°, the total power is smaller than the total base power. As the forward speed continues to increase, the total power continues to increase, exceeding the total reference power. Because of the addition of wing, the maximum flight speed decreases as the drag increases, and it is the minimum when the mounting angle is 20° and the maximum when the mounting angle is 10°.

It can be seen that in the medium speed range between 80 km/h and 260 km/h, the wing increases the lift-to-drag ratio of the helicopter. When the wing takes a larger aspect ratio (AR), the helicopter's maximum L/D is relatively less, as shown in Fig.9. At the lower speeds, the addition of the wing is not conducive to improve the flight performance of the helicopter. There is a significant increase in L/D up to 40% and a decrease in required power down by 10%—15%.

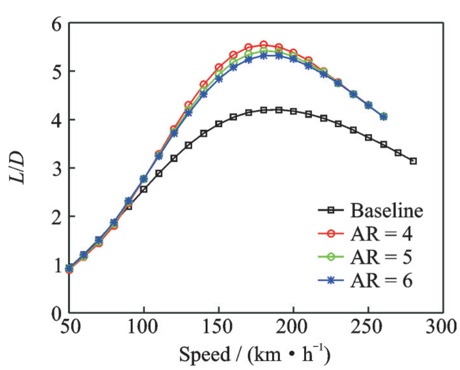

Fig.9 L/D vs speed at 90% Ω_R, ϕ_W=13°

3.3 With propeller and wing

In the above sections, the changes of helicopter power and lift-to-drag ratio when propeller and wing separately installed ate studied. This section determines the wing and propeller compounded helicopter by comparing the increase and decrease of power and lift-to-drag ratio and their impact on flight performance. The previous papers have proved that the take-off weight and the flying height have a significant influence on the change of the total required power and the helicopter lift-to-drag ratio. As can be seen that the addition of wing and propeller increases the total power of the helicopter at low speeds (< 130 km/h). At this time, conversion to a compound helicopter is not conducive to improve the flight performance of the helicopter. As the speed further increases, there is a vast reduction in total power for $C_W = 0.0065$. At speeds between 180 km/h and 210 km/h where L/D is maximum, the reduction in power is 20% and 26% respectively, as shown in Fig.10. When the speed further increases, the reduction continues to 35% at the speed of 280 km/h at 90% Ω_R.

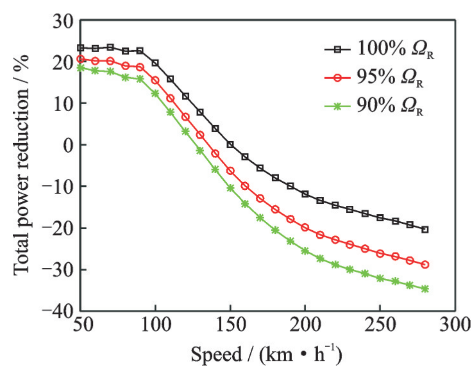

Fig.10 Power reduction vs speed at $C_W = 0.0065$

Compared with the change of total power, the increase of lift-to-drag ratio corresponds to the changing trend. The increase in L/D is continuous above the speed of 130 km/h where the trend further seeks height with decreasing rotor speed. Increase in L/D ratio is a maximum of 51% for 90% Ω_R at the highest forward speed of 280 km/h. In the region of the maximum L/D, the change is observed by 30% in Fig.11.

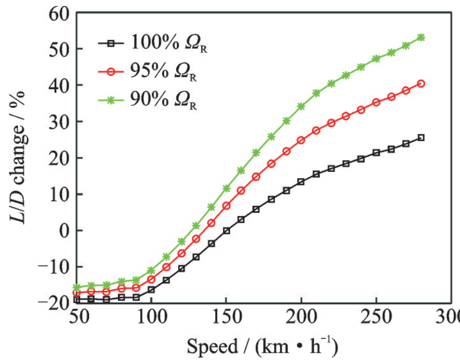

Fig.11 L/D change vs speed at $C_W = 0.006\,5$

At low speed, the total power trend is above the baseline for all the heights as parasitic drag and profile drag are higher. However, as the speed increases, the required power decreases and comes to the minimum value at speed of 160—210 km/h. The trend increases again with the speed but is still lower than baseline, i. e. without propeller and wing. The curve is almost the same for H=0 m and H =1 000 m as there is not significant decrease in air density. However, at H=2 000 m there is a serious decrease in air density because of which parasitic drag and profile drag decrease and lead to a decrease in power required by helicopter to fly and could trim to a maximum speed of 400 km/h, as observed in Fig.12. The reduction in power required at H=2 000 m can be observed by 23% at the speed of 320 km/h.

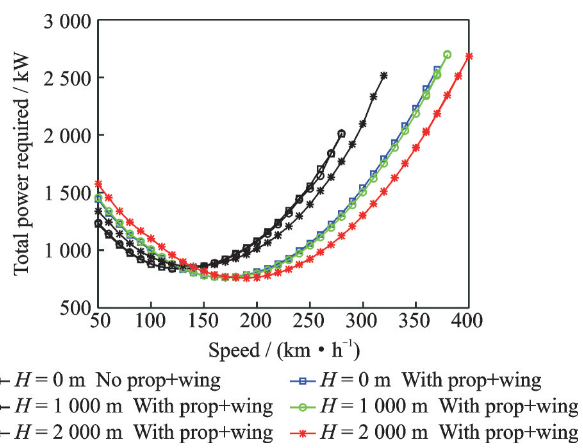

Fig.12 Total power vs speed at 90% Ω_R at $C_W = 0.006\,5$

The impact of helicopter take-off weight on performance improvement when adding wing and propeller is shown in Fig. 13. Take 90% of the rotor speed and the degree of reduction when the weight coefficients are 0.006 5, 0.007 4 and 0.008 3. At low speeds, the addition of wing and propeller increases the total helicopter power. Under the lower weight coefficient, the required power reduction is the largest. When the weight coefficients are 0.006 5, 0.007 4 and 0.008 3, the maximum power saving speeds are 280, 280, 310 km/h respectively, which are reduced by 35%, 35% and 39%, respectively, as shown in Fig.13.

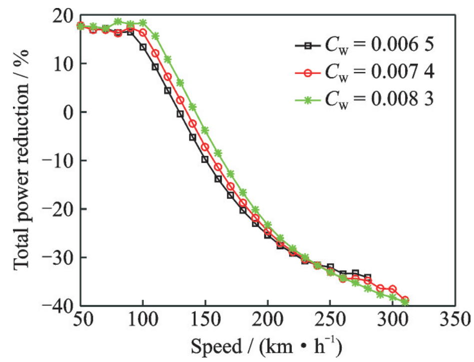

Fig.13 Total power reduction vs speed at 90% Ω_R

4 Conclusions

The UH-60A helicopter is taken as the research object. By constructing the rotor model, fuselage model and tail rotor model, the flight dynamics model of the helicopter is established, and its correctness is verified. On this basis, the aerodynamic model of the propeller is introduced, and a forward flight trim model of the compound helicopter is constructed by the dynamic model of the wing to calculate the forward flight performance of the helicopter. The following conclusions are obtained:

(1) The thrust provided by the propeller is mainly used to balance the drag of the fuselage. The helicopter has better performance when 80% of thrust is shared by the propeller. L/D has a higher value at a lower radius, but there is a limitation for the minimum radius. The propeller can increase the maximum forward speed of the helicopter.

(2) The total power of the helicopter is reduced as the installation angle of the wing increases but the maximum speed of flight decreases. The L/D ratio decreases when the wing takes a larger aspect ratio but is higher than the reference helicopter. The larger the wing area is, the better the perfor-

mance of the rotor will be improved, but the drag is also increased accordingly.

(3) Use of a wing only decreases the maximum speed of a helicopter so a propeller is required to increase the thrust.

(4) The wing and propeller can be further unloaded to improve the flight performance of the high-speed forward flight, and it has a better effect on reducing the total power, increasing the helicopter's lift-to-drag ratio and improving the helicopter's maximum forward speed.

(5) Increase in L/D is maximum when the speed of the main rotor is decreased. At 90% Ω_R, the L/D increment (more than 50%) and the total power reduction (more than 30%) are maximum. Further reduction in rotor speed may cause rotor inefficient.

(6) Higher altitude results in shift of maximum flying speed to 400 km/h with reduction in required power by 23% at 2 000 m above sea level.

(7) Decrease in weight coefficient reduces the required power by helicopter at slower rotor condition (90% Ω_R) but larger weight coefficient can fly at the speed of 310 km/h at sea level.

References

[1] ORMISTON R A. Revitalizing advanced rotorcraft research and the compound helicopter[J]. Journal of the American Helicopter Society, 2016,120: 1-23.

[2] YEO H, JOHNSON W. Aeromechanics analysis of a heavy lift slowed-rotor compound helicopter[J]. Journal of Aircraft, 2007,44: 501-508.

[3] YEO H, JOHNSON W. Optimum design of a compound helicopter[J]. Journal of Aircraft, 2009, 46: 1210-1221.

[4] FLOROS M W, JOHNSON W. Performance analysis of the slowed-rotor compound helicopter configuration[J]. Journal of the American Helicopter Society, 2009,54: 022002.

[5] SILVA C Y H, JOHNSON W. Design of a slowed-rotor compound helicopter for future joint service missions[C]//Proceedings of American Helicopter Society Aeromechanics Specialist's Conference. San Francisco:[s.n.], 2010.

[6] MOODIE A M, YEO H. Design of a cruise-efficient compound helicopter[J].Journal of the American Helicopter Society, 2012,57: 032004.

[7] REDDINGER J, GANDHI F. Physics-based trim optimization of an articulated slowed-rotor compound helicopter in high-speed flight[J]. Journal of Aircraft, 2015,52(6): 1756-1766.

[8] SEKULA M K, GANDHI F. Effects of auxiliary lift and propulsion on helicopter vibration reduction and trim[J].Journal of Aircraft, 2004,41(3): 645-656.

[9] ZHANG Y, CIU Z, HAN D. Flight performance of helicopter with gruney flaps[J]. Acta Aeronautica et Aeronautic Sinica, 2016, 37(1): 2208-2217.

[10] PETERS D A, HAQUANG N. Dynamic flow for practical applications[J].Journal of the American Helicopter Society, 1988,44(4): 64-68.

[11] JOHNSON W. Helicopter theory[M]. New York: Dover Publucation, 1994: 222-238.

[12] Aerodynamics for Student. Propulsion[EB/OL]. (2019-05-15). http://www. aerodynamics4students. com/propulsion/blade-element-propeller-theory.php.

[13] GUDMUNDSSON S. General aviation aircraft design: Applied methods and procedures[M]. [S. l.] : Butterworth-Heinemann, 2013.

[14] HILBERT K. A mathematical modeling of UH-60 helicopter: Technical Report NASA-TM-85890[R]. [S. l.]:NASA,1984.

[15] NAGATA J, PIOTROWSKI J, YOUNG C, et al. Baseline performance verification of 12th year production UH-60A black Hawk helicopter: USAAEFA Project No. 87-32[R]. [S.l.]:[s.n.],1989.

[16] YOE H, BOUSMAN W, JOHNSON W. Performance analysis of a utility helicopter with standerd and advanced rotors[J]. Journal of American Helicopter Society, 2004,49(3): 250-270.

[17] HAN D, PASTRIKAKIS V, BARAKOS G. Helicopter performance improvement by dynamic blade twist[J]. Aerospace Science Technology, 2016, 58: 445-452.

[18] THEODORSEN T, STICKLE G, BREVOORT M J. Characteristics of six propellers including the high-speed range[R]. Washington: Langley Memorial Aeronautical Laboratory,1937.

Authors Dr. **SHAH Suman** received B. Tech. in mechanical engineering from National Institute of Technology-Warangal (NITW), Warangal, India, in 2016. He completed his master of engineering in aircraft design from Nanjing University of Aeronautics and Astronautics (NUAA), Nanjing, China with his research focused in helicopter performance analysis in 2020. Currently he is pursuing his Ph. D. at University of New South Wales

(UNSW) at Australian Defense Force Academy (ADFA), Australia conducting his research on use of ultra-high molecular weight polyethylene (UHMWPE) based composite material for low velocity collision and armor development.

Prof. **HAN Dong** has engaged in scientific research in the field of aircraft design, helicopter dynamics and its control, smart rotor, flight performance of rotorcraft, design of unmanned rotorcraft, and aerial robot at NUAA.

Author contributions Dr. **SHAH Suman** designed the study, completed the modeling process, improved the model, verified with the existing experimental data and got results from the analysis. He also wrote the manuscript. Prof. **HAN Dong** provided background of the study and contributed to the design and discussion of the study. Mr. **YANG Kelong** helped to troubleshoot various problem while modeling and data analysis. All authors commented on the manuscript draft and approved the submission.

Competing interests The authors declare no competing interests.

(Production Editor: SUN Jing)

降转速复合式直升机的性能分析

SHAH Suman, 韩 东, 杨克龙

(南京航空航天大学航空学院, 南京 210016, 中国)

摘 要: 研究了降转速复合式飞行器在高速飞行条件下的旋翼性能。建立了复合式直升机前飞性能的计算模型,确定了合适的机翼和螺旋桨参数。对螺旋桨、机翼和旋翼不同组合时的性能进行了预测。研究了3种不同的叶尖速度和载荷分布。结果表明,螺旋桨提供80%的推力并由机翼分担升力,以最大速度前飞时具有较好的性能和最大的升阻比。计算了在海平面、1 000 m和2 000 m高度巡航时旋翼、螺旋桨和机翼的性能。除了在低速飞行状态机翼接近失速时,旋翼、螺旋桨和机翼的功耗主要来自型阻。飞行高度的增加使旋翼的升力转移到机翼上,降低了总的需用功率,并使最大飞行速度超过了400 km/h。

关键词: 复合式直升机; 机翼; 螺旋桨; 飞行性能; 升力分布; 拉力分布